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THE WEATHERING OF COAL

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CONTENTS

		Page
I.	Introduction	2
II.	Coal Storage	3
III.	Historical Review	5
IV.	Storage Conditions	11
V.	Change in Weight	17
VI.	Change in Calorific Value	23
VII.	Conclusions	31

I. Introduction [1]

In February, 1908, there was published by the Engineering Experiment Station of the University of Illinois, Bulletin 17, entitled "The Weathering of Coal." This publication embodied the results of a series of experiments which were intended at the time to be introductory to an extended study of the subject. As was stated in the text (page 14), the experiments were of a preliminary nature, undertaken mainly to gain information for carrying out more elaborate and comprehensive tests. A number of circumstances made it evident to the writers of this bulletin that it would be advisable to make the work undertaken at that time of a purely preliminary nature; for example, it was decided to make use of relatively small samples, the amount being approximately 20 pounds each. It was thought that the indications given by these samples would serve the purpose of avoiding serious mistakes when tests upon larger masses were made. Moreover, while these experiments were in progress, data from another source accumulated, establishing the fact that a rapid deterioration occurred in the coal in the first few days after breaking out from the seam. This fact promised to have a very important bearing upon the changes which ordinarily would be attributed to weathering losses. This phase of the subject was carried out simultaneously by Mr. W. F. Wheeler and was included in the bulletin noted above under the title "Deterioration of Coal Samples." The effect of such deterioration was not established in time to incorporate the procedure indicated by the fact of such losses, in the experiments on the weathering samples. These fundamental reasons are sufficient to indicate the preliminary nature of the first bulletin. It has since been possible to continue the work in a far more satisfactory manner by making use of the experience already gained in the first experiments. The subject, as here presented again under the same title, has the justification, it is hoped, of being fairly well-rounded and complete in so far as is possible by making use of the experience and knowledge of modifying conditions available at the present time. In one phase of the subject, however, it is far from complete. The subject of weathering can not be gone into without involving also the subject of spontaneous combustion. It is along this latter line that the work is being continued, and it is hoped soon

[1] Credit is due Mr. W. F. Wheeler for the greater part of the work embodied in this bulletin. Mr. Wheeler died Nov. 18, 1909.

to bring those experiments to a stage where the results will justify their publication under that title.

II. Coal Storage

The storing of coal has become more and more of a necessity in the last few years, owing to market conditions, occasional labor difficulties at the mines and on the railroads, and the crowding of transportation facilities. Of these causes, the first is probably of chief importance. It is due to the variable demand for coal for domestic consumption, which necessitates either a much higher rate of production during the winter months or else the providing of sufficient storage capacity to carry over coal produced in the dull season. Especially is this true in the case of anthracite coal, which suffers the most from a variable demand owing to the fact that a larger proportion of it is used for domestic purposes. Anthracite requires much more expensive plants for its preparation than ordinary bituminous coal, and thus offers greater inducements for the operators to keep the rate of production near the capacity of their equipment. One means of doing this is by inducing the consumers to store coal in the summer months. The scheme at present used for this purpose is a sliding scale of prices with a fixed advance in price per ton for every month from April to September. This plan has worked admirably for a number of years, probably ten million tons of coal being stored each summer by consumers and coal dealers. The anthracite coal companies themselves have a combined storage capacity for about seven million tons, or approximately one tenth of the present annual production. This storage capacity is in very large units, the piles containing from 50 000 to 400 000 tons each.

The bituminous coal producers have a more uniform demand throughout the year for all sizes and grades of their product than the anthracite producers can expect. Large power plants, naval coaling stations and railroads are the principal interests storing bituminous coal, except around the great lakes. At nearly all the cities at the head of lakes, the coal companies themselves store great quantities of coal during the season of navigation. Part of this coal is for local consumption, but a larger part of it is for reshipment by rail.

While market conditions offer one of the principal reasons for storing coal, large manufacturing establishments, most power plants

and various other coal users feel compelled to have on hand a reserve supply that will enable their plants to run without interruption in case of strikes, car shortages and other unforeseen circumstances. For this purpose the amount of coal necessarily stored at different plants varies from a few hundred to a few thousand tons.

Anthracite is the nearest approach to an ideal coal for storage. It is practically unaffected by the weather. It is broken somewhat by handling, and at most of the larger storage plants it must be re-screened as it is reloaded. It is not subject to spontaneous ignition, and in consequence there is practically no limit to the size of the piles in which it can be stored. With bituminous coal, the case is different. Most bituminous coal will ignite spontaneously if placed in large enough piles; all of it suffers more or less disintegration during storage and rehandling. Only the coals least liable to fire and those that stand rehandling the best are stored to any extent by the coal producers. Many of the railroads, power plants, factories and naval coaling stations, however, are forced to store coal that is easily affected by the weather and subject to spontaneous ignition. The greatest losses due to coal storage are due to the firing of the stored coal. The atmospheric oxidation of the coal is going on slowly all the time at ordinary temperatures, and continues with increasing rapidity at higher temperatures, until in many cases it results in the ignition of the coal. Thus it must be seen that coals most readily oxidized by the air are most prone to spontaneous ignition, and are the ones that lose the most in heating value. Any heating of the coal in the pile represents just so much heat that will not be available later under the boiler. Most of the atmospheric oxidation does not produce any sensible heating, but it results, nevertheless, in an appreciable loss of heat units by the coal. The changes taking place in stored coal may be divided into two classes: (1) oxidation of pyrite, marcasite and other inorganic constituents; and (2) the direct oxidation of the organic matter of the actual coal. To the changes in the inorganic matter most of the visible changes are due,—the iron sulphide changes into sulphate of iron and sulphuric acid, the latter of which unites with the calcium and magnesium carbonates, almost invariably present in the coal, to form gypsum and magnesium sulphate. All such changes result in a large increase in volume and a marked disintegration of the coal, and they will also result in a considerable increase in the weight of the coal in many instances unless removed by the

leaching action of water. The other changes due to the direct oxidation of the coal substances cannot be detected by the eye except in rare instances where they have progressed nearly to completion, as in the case of a sample of coal taken from an outcrop in Peoria county, Illinois. (See Table 15). This particular coal has changed from a lustrous black bituminous coal to a dull brown lignite as far as appearances go. It is, however, the invisible change due to this direct oxidation of the carbon and available hydrogen of the coal substance and the absorption of the oxygen by unsaturated hydrocarbons that plays the principal part in promoting spontaneous ignition and in causing weathering losses in heating value.

III. Historical Review

For the past fifty years, many chemists and engineers have been studying and observing the chemical and physical changes occurring in stored coal. Professor Grundmann [1] of Tarnowitz, Germany, published the first record of any extensive experiments to determine the weathering losses of coal. He made use of the percentage of ash in the coal to determine the change in weight that took place, and with that as a basis, decided that the coal in a pile of 300 tons lost 58 per cent in weight in a period of nine months, the greater portion of the loss taking place soon after the coal was placed in storage. Other experiments by the same writer show losses almost as great. Such changes are, however, hardly confirmed by his other observations, i. e., that the specific gravity and the composition of the coal substance, the actual coal, remained unchanged. It is almost a certainty that the explanation for his extreme figures is to be found in a lack of uniformity of the samples employed. The chief benefit derived from Grundmann's experiments comes from the interest which they aroused in the subject and the investigations they initiated.

Reder [2] at Ornabruck, Germany, was among the first to follow up Grundmann's work. Using the same kind of coal, he found a small increase in weight and no practical changes in the coal. In the case of one German coal, however, he found a loss of about 4 per cent in the calorific value. Professor Varrentrapp [3] of Brunswick, Germany, worked at temperatures between 100° C. and 300° C. and found a

[1] Carnall's Ztsch. Vol. X, p. 236, 1862; Oest. Ztsch. f. Berg, u. Hütt Vol. XV, p. 270, 1867; Kerperly Bericht, 1866, p. 33.

[2] Oest. Ztsch. f. Berg, u. Hütt. Vol. XV, 1867; Reder, Ztsch. d. Ver. deutsch Eng. Vol. X, p. 698, 1866.

[3] Dingler's Jour. Vol. 175, p. 156; Vol. 178, p. 379, 1865.

very rapid oxidation of the coal. In three months at 284° C., coal was reduced completely to ash; and at 160° C., he claims to have oxidized more than one-half of the carbon in the same length of time. Present knowledge of the subject, however, would indicate that the temperature of the coal itself must have been considerably higher than 284° C. That would easily have been possible even though the temperature of the oven or containing vessel did not rise above that temperature. In our own experiments on spontaneous ignition, coal kept in an oven at 110° C. has oxidized rapidly enough to raise its own temperature nearly to 200° C. In experiments with coal under ordinary storage conditions, Varrentrapp reports losses in weight and calorific value of 33 per cent for coal exposed to the weather and 12 per cent for that kept under cover. The same coals are said to have lost 45 and 24 per cent respectively in value for gas making. From the lack of confirmation by subsequent work, it seems that improper sampling or some other error must be sought in explanation of the excessive losses reported.

In 1865, Fleck [1] analyzed a series of six German coals that had been in a cabinet for eleven years, exposed to the air. The samples were not uniform as regards ash contents, but on the ash and water-free coal, the samples all showed a small decrease in carbon and available hydrogen and an increase in oxygen. Richters [2] soon afterward investigated the action of oxygen on coal at ordinary and moderately raised temperatures. His conclusions are that the coal absorbs oxygen and gives off carbon dioxide and water in smaller amounts, thus leaving a portion of the oxygen combined with the coal substance, causing an increase in weight. The reaction was found to be more rapid at slightly raised temperatures, and it seemed to be unaffected by the amount of moisture present except that in the presence of pyrites the coal was more disintegrated and seemed more liable to heat. Richters found three different coals to lose as much as 3.6 per cent in calorific value in two weeks at about 80° C. He concludes that pyritic coals oxidize most when damp, and that coals free from pyrite are most affected if kept dry. Richters also placed several hundred pounds of fresh coal from different mines in baskets containing about one hundred pounds each, and buried these baskets in a large unprotected pile of coal. After about ten months' storage,

[1] Technik d. Steinkohlen Deutschlands, Vol. II, p. 221, 1865.
[2] Dingler's Jour. Vol. 190, p. 398, 1868.

he found changes in weight varying from a loss of .5 per cent to a gain of 2.0 per cent in the various lots.

Professor Fischer [1] of Gottingen comes to the same conclusion that was reached by Fleck and Richter, viz., that weathering and spontaneous ignition are due to oxidation of the coal substance and also of the pyrite and marcasite.

Groves and Thorp [2] give practically a summary of the previous investigations as to the nature and extent of weathering, but they also ascribe part of the loss to the liberation of combustible occluded gases and state that serious explosions on coal-laden vessels have resulted from this source. They recommend the shipment of only lump coal as a means of preventing fires on shipboard.

E. C. Pechin [3] made analyses of Connelsville coke after two and five years' storage out of doors and found no changes. He states that the best anthracite will lose part of its carbon, and bituminous coal will lose from 10 to 25 per cent by weight upon exposure, but cites no data in proof of his statements. Professor J. W. Langley, in a discussion of the same paper, offers the opinion that the losses sustained by different types of coal during storage are proportional to their ignition temperatures. He mentions Grundmann's and Varrentrapp's experiments as proof.

R. L. Rothwell [4] says, as a result of practical observation, that there appears to be no loss in anthracite coal or eastern bituminous coal except in case of small sizes of bituminous coal. He also reviews Richters', Grundmann's and Varrentrapp's work.

R. S. Hale and H. J. Williams [5] report an investigation where they exposed three small samples of bituminous coal for eleven months and found a loss in calorific value of from one-half to one per cent. These samples were from Pennsylvania, Virginia and Maryland.

John Macauley, [6] general manager of the Alexandra Docks and Railway, Newport, England, comes to the conclusion, after making practical steaming tests with locomotives, that English coal depreciates from ten to twelve per cent per year in steaming value when stored in England. He states as his opinion that the loss in hot climates would be more nearly twenty-four per cent. If the coal were stored under water, less breakage would result; three per cent is esti-

[1] Gas World, April 13, 1901.
[2] Chemical Technology, Vol. I, p. 82.
[3] Trans. Am. Inst. Min'g Engs., Vol. I, p. 286, 1872.
[4] Trans. Am. Inst. Min'g Engs., Vol. II, p. 150, 1873.
[5] Trans. Am. Soc. Mech Engs., Vol. XX, p. 333, 1899.
[6] Prac. Eng., Oct. 2, 1903. Eng. (London), Oct. 30, 1903.

mated as being sufficient to cover the losses that would be sustained in one year. He bases his estimate for submerged coal on results obtained by burning coal recovered from wrecks, coal that had been under water continually for as long as ten years. There seems to be no certainty as to the original quality of the sunken coal, and such being the case, comparisons made with fresh coal can be only approximations.

Dr. James P. Kimball,[1] of Lehigh University, gives an excellent review of the work done by Grundmann, Varrentrapp, Richters and others, prior to 1879. He also goes thoroughly into the changes due to oxidation of pyrite and marcasite and considers that their effects have been underestimated. He thinks that the oxidation of marcasite especially is of as much importance as the oxidation of the coal itself. Several instances are given where good coking coal has lost its coking property on account of weathering action. Weathering of coal in the seam is mentioned, and analyses of coal from the Coalton or No. 7 seam in Kentucky are presented to show the extent of weathering due to exposure in the mine and also to lack of sufficient cover. As only the proximate analyses are given, together with the analyses of the soluble mineral matter, no material changes are made evident except an increased amount of sulphates of iron and calcium.

In an article by G. Arth,[2] a report is made of experiments with small coal stored in the air and under water. The conclusions given are that for a period of one year the changes in composition and calorific value are too small to receive practical consideration.

Several practical engineers consider that coal stored for use in locomotives loses from 10 to 50 per cent in heating value, but none of them presents data.

Practically all coal is stored in piles in the open air. The Western Electric Company [3] at their Hawthorn plant in Chicago has, however, put in concrete-lined bins, or rather reservoirs, with a capacity of about 15 000 tons of coal. In these bins the coal is kept constantly submerged, primarily for protection from spontaneous ignition. Analyses of coal stored at this plant for two years both under water and in the open air show an advantage of 1.9 per cent in heating value in favor of the coal stored under water.

[1]Trans. Am. Inst. Min'g Engs. Vol. VIII, p. 204, 1879.
[2]Bulletin Soc. Chem., Vol. XI. p. 619-622, 1894.
[3]Eng. News, Vol. 60, p. 729, 1908.

Several experiments have been made in the last few years by the coaling stations of the United States Navy and also the English Navy to determine the advantages, if any, to be obtained by storing coal under water, but as yet no reports of these experiments have come to our notice.

Dr. Habermann [1] states that the weathering and spontaneous ignition of coal are due to the property of the coal substance for absorbing oxygen. He gives the results of a series of experiments on spontaneous ignition where coal placed in a fire-brick retort at 50° C., and supplied with air at an ordinary temperature, practically ignited in forty-eight hours. Dr. Habermann also found great loss in gas making, coking and heating value.

An editorial in Power [2] gives Heidepin credit for showing that spontaneous ignition and weathering are due to direct oxidation of the coal substance and to the oxidation of pyrites, as Leibig supposed. Bunte also credits the phenomena to a direct oxidation and absorption of oxygen by the coal. The smaller sizes and the most porous coal are said to be affected the most. The absorption of oxygen may result in a gain in weight of as much as four per cent. W. A. Powers, chief chemist of the Santa Fe Railroad, in 1907, carried out an investigation of the weathering losses of the coals used on that road. These coals covered a wide range of country, samples being tested from Illinois, Missouri, Kansas, Colorado and New Mexico. One hundred-pound lots of coal were stored in the open air and under water for a period of seven months. The coal stored under water is said to have lost from .26 per cent to 5.92 per cent in weight, and from .56 per cent to 8.75 per cent in calorific value. The coal stored in the open air lost in weight .60 per cent to 4.78 per cent and 1.10 per cent to 9.40 per cent in calorific value.

E. A. Tessenden and J. R. Wharton [3] state that the higher the percentage of volatile matter in a coal, the more prone it is to spontaneous ignition and the greater the weathering losses it will sustain. Occluded combustible gases, high sulphur content, small size, presence of moisture, high temperature, and free access of air are all given as causes of weathering and fires. Mention is made of the general schemes commonly employed for handling stored coal in open

[1] Jour. Gasbel, Vol. 49, p. 419.
[2] Power, Vol. 27, p. 437, 1907.
[3] Bulletin University of Mo., Eng. Series, Vol. 1, 1908.

piles and in covered bins. They also note the plans used and proposed to reduce the liability of spontaneous ignition.

In their experimental work only one kind of coal, (from Staunton, Illinois) was used, but it was subjected to different storage conditions, namely, out of doors, in a warm dry room, and under water. Three sizes were prepared and used, making nine samples in all. The coal stored out of doors is said to have disintegrated badly, while that in water and in the dry room was not much damaged. Only the calorific value of the coal as sampled is made use of in determining the weathering losses. The results reported show the futility of trying to make accurate comparisons of the calorific values of fuels on an air-dry basis, with variable ash content. It seems practically certain that the exceedingly high losses found are due largely to discrepancies in the amounts of moisture and ash in the coal samples taken for analysis. Taking the average values for all of the samples used, the losses found in four months were 4.3 per cent for coal under water, 7.0 per cent for coal in dry rooms, and 14.1 per cent for exposed coal. Further experiments are being carried out on samples of Missouri coal, and in them the moisture and ash will be determined in addition to the calorific value.

In the fall of 1906, Mr. N. D. Hamilton,[1] under the direction of Professor S. W. Parr, began a preliminary series of experiments at the University of Illinois to determine the nature and amount of the chemical changes that take place in coal when it is exposed to the weather and also when it is more or less protected. This work extended over a period of nine months. The samples used were collected at the retail coal yards in Champaign and Urbana, Illinois. Most of the coal had been out of the mine for two weeks or more before sampling, time enough for material changes to have taken place, as will be shown later. There was some question as to the exact identity of the coal in the case of a few of the samples. The coal was not sampled and handled in such a manner as to make it representative of any particular product of the mines supplying it. However, that is of but slight importance, except that all of Mr. Hamilton's samples represent small coal and not lump coal, as was reported in some cases. It does not seem at all probable that the so-called lump coal would give the same results likely to be obtained on storing lump coal, as Mr. Hamilton broke the lumps up into pieces about one inch in diameter before storing. It seems very probable also that the

[1]Bulletin 17, Eng. Exp. Sta., 1907.

changes taking place in such small lots of coal (about twenty pounds were used in each test), would be very much greater than would occur in actual storage practice, where it would be the exception to find a pile containing as little as two hundred tons. Mr. Hamilton's figures probably would represent only the outside layers of actual coal piles. If the coal in the storage pile becomes very warm, or ignites spontaneously, then the loss and chemical changes taking place may be in excess of changes in the small samples, but that will be the exceptional case. The various samples taken from the 20-lb. lots for analysis were not representative of even that small amount, as great variations occur in the ash and sulphur percentages reported.

In the last three investigations by Mr. Powers, Messrs. Tessenden and Wharton, and Mr. Hamilton, the Parr calorimeter was used exclusively, and probably it is responsible for some erroneous calorific values, owing to the effects of variable amounts of ash and sulphur on the rise in temperature observed in that instrument, some of which were not fully appreciated at the time. A study has been made recently [1] of these errors and it is now possible to correct for them with a fair degree of accuracy.

No account was taken of the amount of disintegration or of changes in weight during Mr. Hamilton's investigation. The tentative conclusions from his work were that coal stored dry or in the open would lose from 2 per cent to 10 per cent in calorific value in a period of nine months, the rate of loss being greatest at first. The coal stored under water did not lose appreciably in calorific value.

IV. Storage Conditions

Object of the Experiments.—The object of these experiments was to determine the change in weight, the change in calorific value and the amount of disintegration that are liable to occur in the grades of coal found in Illinois and neighboring states under different conditions of storage, (1) in the open air in piles; (2) in covered bins; and (3) under water.

Source of Coal Tested.—The coal used in these experiments came entirely from Illinois mines. (1) For the principal series, coal from Vermilion, Sangamon and Williamson counties was used, as it was considered representative of about as great a difference in character as is shown by the coals of the State. The results on this series are

[1] Jour. Am. Chem. Soc., Vol. 29, p. 1606, 1907.

embodied in Tables 1 to 12 inclusive. (2) Piles of coal of approximately 300 or 400 tons in amount from Christian and Fulton counties were available, and these were examined after they had been exposed for about six months. The results are shown in Table 13. (3) A 15-ton lot of Vermilion county coal had been piled on the ground for 2½ years. Occasional analyses of it had been made and also of some of the same lot which had been stored under water in a barrel by Mr. Hamilton. This pile was resampled; the results of both analyses are embodied in Table 14. (4) A series of samples was taken from old pillars long exposed to mine conditions, as well as the more extreme case of an outcrop. These results are embodied in Table 15. (5) The Commonwealth Edison Company early in 1908, stored nearly 40 000 tons of coal from Williamson and Franklin counties. Advantage was taken of their offer to supply us with samples for experimental purposes. The results are embodied in Table 16.

Storage Conditions, Sizes of Coal and Sizes of Piles Employed.— As was noted, the principal series consisted of car lots from representative mines in Vermilion, Sangamon and Williamson counties. Carloads of both screenings and nut coal were shipped to the University in January, 1908. One-half of each carload was piled out of doors to a uniform depth of about three and one-half feet, in shallow bins with earth floors. The other half carload was put in covered wooden bins, partly open on two sides, with board floors one and one-half feet above the ground. The coal filled these bins to a depth of about five feet. (See Fig. 1 and 2 for view of storage bins.) Facilities were not available for the storage of any large quantity of coal under water, and on that account only about one hundred pounds from each car was stored in this way. Stone-ware jars were used for containers. The jars, loosely covered to keep out the dust and to retard evaporation, were placed in the basement of the Chemistry building, where the temperature did not vary much from 70° F. The coal from Christian and Fulton counties was not inspected when it was stored, as it was not intended for experimental purposes. It was in piles three to seven feet in depth containing about 500 tons of screenings, entirely exposed to the weather. The coal stored by the Commonwealth Edison Company was in three piles, the main one containing about 25 000 tons of egg coal over three inches and less than six inches in diameter. The second pile contained 3500 tons of nut coal, and the third about 4500 tons of No. 1 washed coal. The

Fig. 1

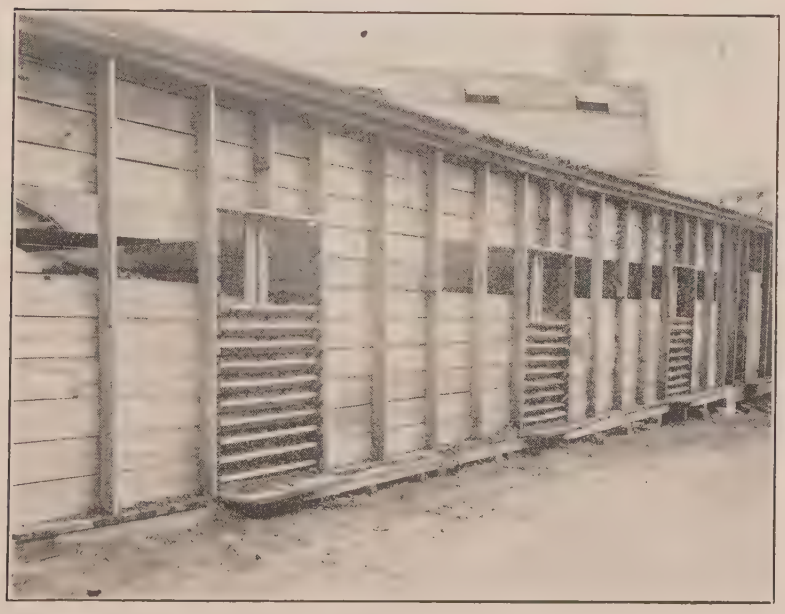


Fig. 2

pillar coal and that from the outcrop in Peoria county are all samples representing the entire thickness of the coal seam. The conditions and time of exposure are given in the tables following, (p. 15).

Sizing Tests.—It was thought that the amount of disintegration suffered by the coal would probably be one of the principal sources of loss, as it might change a coal of suitable size for use in a certain plant to a smaller size than could be used economically. When the coal was stored samples were screened to find the proportion of the various sizes from ⅛ inch in diameter up to 1 inch and over. The screen used was of the revolving or trommel type, made of perforated steel plate. (See Fig. 3.)

Fig. 3

The relative sizes of coal before and after storing for one and one-half years are shown in Tables 1 and 2 and also graphically in Fig. 4 and 5.

Explanation of Tables.—In the columns headed "per cent," Tables 1 and 3, the figures represent the amount of coal between the two sizes given in the same line. The columns headed "cumulative

TABLE 1

SIZING TEST ON NUT COAL

Vermilion County, Illinois

Round Hole Screen		Original Sizes		Exposed Bins 1½ Years		Covered Bins 1½ Years	
Through inches	Over inches	per cent	Cumulative per cent	per cent	Cumulative per cent	per cent	Cumulative per cent
3	1	66.2	.....	42.5	.....	44.2	.....
1	¾	5.0	71.2	8.0	50.5	7.6	51.8
¾	½	7.2	78.4	11.8	62.3	11.7	63.5
½	⅜	4.0	82.4	6.9	69.2	6.7	70.2
⅜	¼	4.0	86.4	6.8	76.0	7.1	77.3
¼	⅛	5.0	91.4	10.9	86.9	10.4	87.7
⅛	0	8.6	100.0	13.1	100.0	12.3	100.0
Total.....	.....	100.0	.....	100.0	.....	100.0	.....
Average diameter		1.458 in.		1.074 in.		1.102 in.	

Williamson County, Illinois

3	1	94.0	.....	70.2	.....	68.5	.....
1	¾	1.6	95.6	5.7	75.9	5.7	74.2
¾	½	1.8	97.4	6.6	82.5	7.1	81.3
½	⅜	.7	98.1	3.1	85.6	4.1	85.4
⅜	¼	.5	98.6	3.2	88.8	3.6	89.0
¼	⅛	.5	99.1	4.6	93.4	4.9	93.9
⅛	0	.9	100.0	6.6	100.0	6.1	100.0
Total.....	.....	100.0	.....	100.0	.....	100.0	.....
Average diameter		1.910 in.		1.532 in.		1.506 in.	

Sangamon County, Illinois

3	1	89.4	.....	64.3	.....	52.0	.....
1	¾	4.1	93.5	6.9	71.2	9.3	61.3
¾	½	3.5	97.0	8.4	79.6	10.8	72.1
½	⅜	1.2	98.2	3.2	82.8	5.7	77.8
⅜	¼	.6	98.8	4.0	86.8	5.8	83.6
¼	⅛	.6	99.4	7.4	94.2	8.1	91.7
⅛	0	.6	100.0	5.8	100.0	8.3	100.0
Total....	.....	100.0	.....	100.0	.....	100.0	.....
Average diameter		1.854 in.		1.442 in.		1.252 in.	

per cent'' give the total amount of coal larger than the smaller of the two sizes given in that line.

The proportion of small sizes in the nut coal is shown to have increased considerably, and the average diameter to have decreased in proportion. The amount of coal that would pass a ½-in. hole

TABLE 2

SIZING TEST ON SCREENINGS

Vermilion County, Illinois

Round Hole Screen		Original Sizes		Exposed Bins 1½ Years		Covered Bins 1½ Years	
Through inches	Over inches	per cent	Cumulative per cent	per cent	Cumulative per cent	per cent	Cumulative per cent
1¾	1	19.0	.....	11.3	.....	11.6	.....
1	¾	8.9	27.9	6.3	17.6	6.3	17.9
¾	½	14.8	42.7	12.9	30.5	12.2	30.1
½	⅜	8.5	51.2	9.3	39.8	9.3	39.4
⅜	¼	11.1	62.3	11.8	51.6	11.8	50.2
¼	⅛	16.4	78.7	21.0	72.6	21.0	71.2
⅛	0	21.3	100.0	27.4	100.0	27.8	100.0
Total.....	.....	100.0	.....	100.0	.....	100.0	.....
Average diameter....		.548 in.		.425 in.		.425 in.	

Williamson County, Illinois

1¾	1	18.9	.....	19.0	.....	14.2	.....
1	¾	9.0	27.9	9.2	28.2	7.0	21.2
¾	½	14.4	42.3	15.4	43.6	13.0	34.2
½	⅜	8.5	50.8	9.5	53.1	9.0	43.2
⅜	¼	10.4	61.2	10.6	63.7	11.4	54.6
¼	⅛	15.4	76.6	17.0	80.7	20.2	74.8
⅛	0	23.4	100.0	19.3	100.0	25.2	100.0
Total.....	.....	100.0	.....	100.0	.....	100.0	.....
Average diameter....		.542 in.		.557 in.		.466 in.	

Sangamon County, Illinois

1¾	1	38.8	.....	15.1	.....	15.6	.....
1	¾	7.9	46.7	9.3	24.4	9.1	24.7
¾	½	13.2	59.9	15.6	40.0	15.6	40.3
½	⅜	6.6	66.5	7.7	47.7	9.7	50.0
⅜	¼	7.2	73.7	9.4	57.1	11.5	61.5
¼	⅛	11.2	84.9	17.2	74.3	19.6	81.1
⅛	0	15.1	100.0	25.7	100.0	18.9	100.0
Total.....	.....	100.0	.....	100.0	.....	100.0	.....
Average diameter....		.768 in.		.498 in.		.518 in.	

was nearly doubled in the case of the Vermilion county nut coal, and in the nut coal from Williamson and Sangamon counties there was seven times as much coal below ½ inch in diameter after one and one-half years' storage as there was originally. The average diameter

of the pieces of coal in all three of these lots was about three-fourths as great after storage as before, the average weight being only about four-tenths as great.

The changes in the screenings are not nearly so great as in the nut coal, but even then they are certainly of as much importance as any of the other changes due to weathering. The average diameter of the coal before and after weathering was calculated on the assumption that the diameter of the coal particles through any certain size of hole in the screen was the average of the diameter of that hole and of the one next smaller, i.e., the diameter of coal through the ½-in. screen and over the ⅜-in. screen was considered to be 7/16-in. There seems to be no advantage in favor of storage in either open or covered bins so far as the amount of disintegration shown by these experiments is concerned. The disintegration is due to the action of frost; to the opening of small cracks originally started at the time the coal was shot in the mine; and also to the oxidation of pyrite and marcasite, resulting in a large increase in volume, and consequently, a breaking up of the pieces of coal. With lump coal intended for sale or reshipment, this disintegration must result in a large decrease in value. While no sizing tests are available as proof, it seems probable from observation that coal kept absolutely dry, and not subjected even partially to the weather (as was that stored in covered bins), would not break up to the extent shown in these experiments. Probably the ideal way to store coal, so far as disintegration is concerned, would be under water, thus obviating the action of frost entirely. The friability of the coal after storage seems much increased, and any rehandling must result in much greater breakage than it would with freshly mined coal.

V. Change in Weight

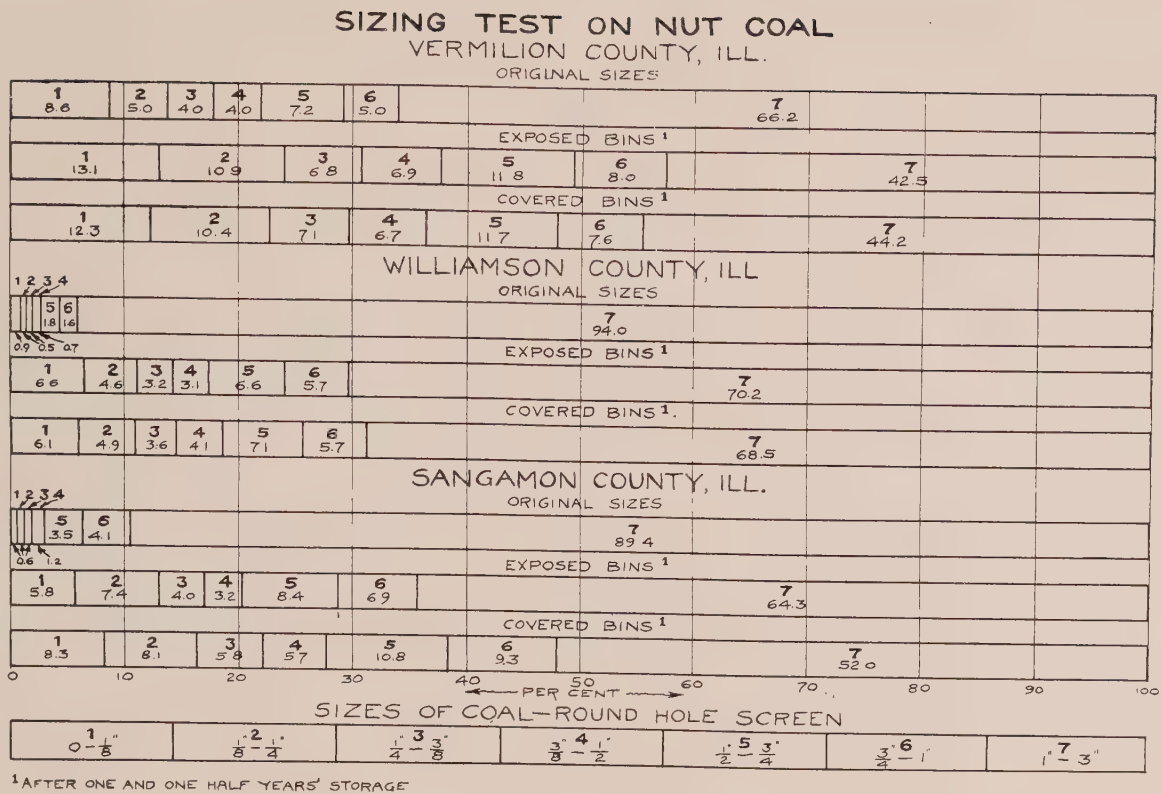
The storage of coal has been thought by some investigators to result in a considerable loss in weight. If the coal heats considerably and fires occur in the storage piles, there is undoubtedly a great loss in weight, but it is still an open question as to how great this change is in storage under fair average conditions. The change in the weight of air-dry or wet coal cannot be considered in this connection. The exact weight of dry coal must be ascertained by some means. The coal must be weighed, and then dried in an oven at some certain temperature for an exact determination of the amount of moisture

in it at the time, as it is not possible to get the coal into such an air-dry condition before and after storage that it will contain exactly the same percentage of moisture each time. The coal in these experiments was weighed, sampled carefully, and the moisture determined at 105° C. The weight of the moisture was then deducted from the weight of the air-dry coal, and the resulting weight of dry coal was used in making all comparisons. The results are given in Tables 3, 4 and 5. The larger samples (Table 3) show a loss of about one and one-half per cent in weight in two cases out of six, the other four show no change within the limits of experimental error, and it is doubtful whether even these two are not chargeable to possible discrepancies in moisture determinations rather than to any actual change in weight. The results of these experiments show only that any change in weight that does occur is very small in amount and is not to be considered unless the coal has heated considerably. Further data along this line are necessary, especially with large samples under actual storage conditions, before any conclusions as to either an increase or decrease in weight would be warranted.

TABLE 3

CHANGE IN WEIGHT OF COAL EXPOSED TO THE AIR

DESCRIPTION	Weight of Coal Dried at 105° C.	Weight of Coal Dried at 105° C.	Change in Weight	
Screenings from	pounds	pounds	pounds	per cent
Williamson Co., Ill.	Weighed Dec. 15, '08	Reweighed June 17, '09		
In open box on roof	311.8	307.0	—4.8	—1.54
In barrel in building	300.7	300.5	—0.2	— .07
Sangamon Co., Ill.	Nov. 27, '08	June 17, '09		
In open box on roof	227.7	224.4	—3.3	—1.45
In barrel in building	235.8	235.9	+0.1	+ .04
Vermilion Co., Ill.	Nov. 11, '08	June 17, '09		
In open box on roof	289.0	288.9	—0.1	—.03
In barrel in building	284.0	284.9	+0.9	+.32



[1] AFTER ONE AND ONE HALF YEARS' STORAGE

Fig. 4

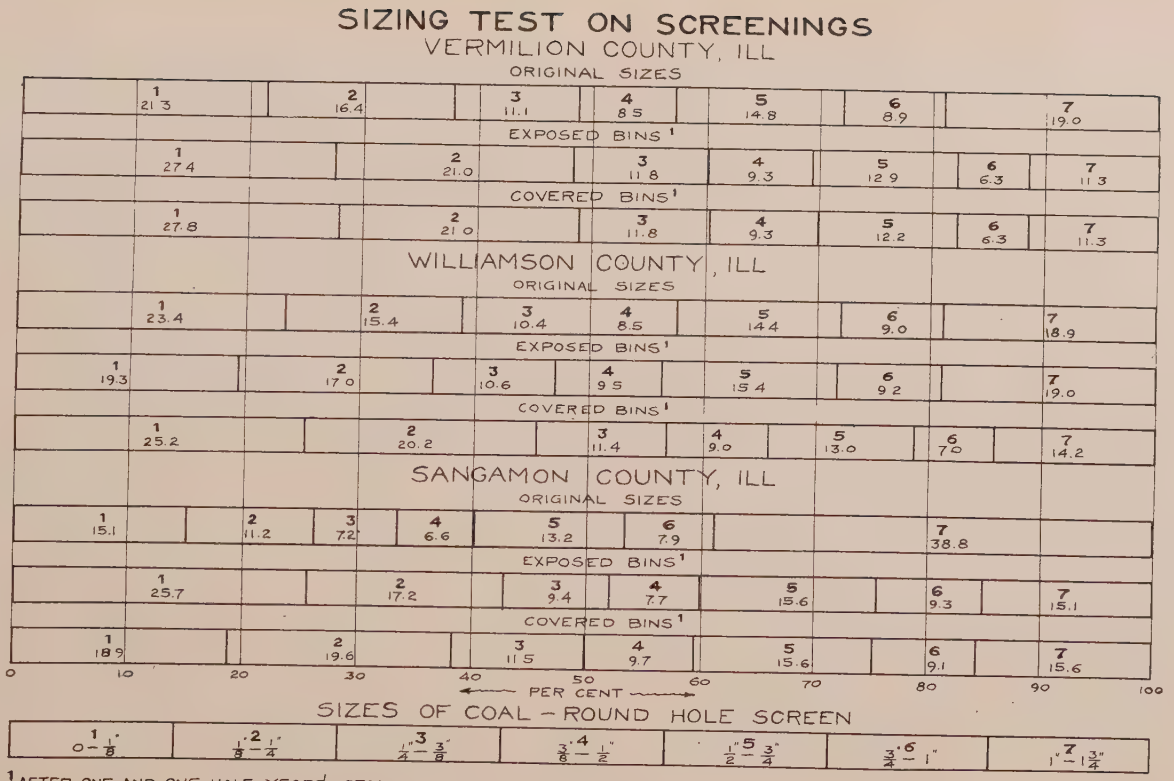

SIZING TEST ON SCREENINGS
VERMILION COUNTY, ILL
ORIGINAL SIZES
1 21.3
2 16.4
3 11.1
4 8.5
5 14.8
6 8.9
7 19.0
EXPOSED BINS[1]
1 27.4
2 21.0
3 11.8
4 9.3
5 12.9
6 6.3
7 11.3
COVERED BINS[1]
1 27.8
2 21.0
3 11.8
4 9.3
5 12.2
6 6.3
7 11.3
WILLIAMSON COUNTY, ILL
ORIGINAL SIZES
1 23.4
2 15.4
3 10.4
4 8.5
5 14.4
6 9.0
7 18.9
EXPOSED BINS[1]
1 19.3
2 17.0
3 10.6
4 9.5
5 15.4
6 9.2
7 19.0
COVERED BINS[1]
1 25.2
2 20.2
3 11.4
4 9.0
5 13.0
6 7.0
7 14.2
SANGAMON COUNTY, ILL
ORIGINAL SIZES
1 15.1
2 11.2
3 7.2
4 6.6
5 13.2
6 7.9
7 38.8
EXPOSED BINS[1]
1 25.7
2 17.2
3 9.4
4 7.7
5 15.6
6 9.3
7 15.1
COVERED BINS[1]
1 18.9
2 19.6
3 11.5
4 9.7
5 15.6
6 9.1
7 15.6
0 10 20 30 40 50 60 70 80 90 100
PER CENT
SIZES OF COAL — ROUND HOLE SCREEN
1 0 – 1/8"
2 1/8 – 1/4"
3 1/4" – 3/8"
4 3/8" – 1/2"
5 1/2" – 3/4"
6 3/4" – 1"
7 1" – 1 3/4"
[1] AFTER ONE AND ONE-HALF YEARS' STORAGE

Fig. 5

TABLE 4

CHANGE IN WEIGHT OF COAL EXPOSED TO THE AIR

Lab. No.	DESCRIPTION		Weight of Coal Dried at 105° C. grams	Weight of Coal Dried at 105° C. grams	Gain in Weight grams	Gain in Weight per cent
	Screenings		Weighed Feb. 14, '08	Reweighed Nov. 17, '08		
1212	Williamson Co., Ill.	Dry	1331	1348	17	1.28
1213	" " "	Wet[1]	1222	1233	11	.90
1214	Sangamon " "	Dry	1099	1114	15	1.36
1215	" " "	Wet[1]	1121	1142	21	1.87
1216	Vermilion " "	Dry	1021	1028	7	.69
1217	" " "	Wet[1]	1056	1061	5	.47
	Nut Coal		Feb. 26, '08	Sept. 16, '08		
1219	Vermilion Co., Ill.	Dry	947	960	13	1.37
1221	Sangamon " "	"	1196	1222[2]	26	2.17
1223	Williamson " "	"	1138	1159	21	1.85
1220	Vermilion " "					
1222	Sangamon " "	Wet	3130	3147	17	.54
1224	Williamson " "					

[1] Water evaporated and left coal dry for last month or six weeks. Considerable ferrous sulphate showed in all samples that had been wet, especially in Lab. No. 1215.

[2] This sample was reweighed Nov. 17, '08, instead of Sept. 16, '08.

TABLE 5

LOSS IN WEIGHT OF AIR-DRY COAL AT VARIOUS TEMPERATURES UP TO 260° C.

Lab. No.	Weight of Sample grams	TOTAL LOSS IN WEIGHT DUE TO HEATING IN AIR				
		1 hour at 105° C. per cent	4 hours at 105° C. per cent	18 hours at 140° C. per cent	14 hours at 260° C. per cent	44 hours at 260° C. per cent
1591[1]	1	5.05	4.82	2.75	22.92	38.3
1592[1]	1	5.65	5.45	2.96	25.00	Lost
1591	2	4.18	4.66	3.07	15.92	34.8
1592	2	4.71	5.08	3.36	14.60	34.3
1551	2	2.89	2.76	.22	19.40	31.3
1567	2	2.74	2.86	1.37	9.92	23.9
1569	1	6.23	6.20	3.66	24.55	48.1
1569	2	6.10	6.09	3.61	19.74	48.3
1569	3	5.95	6.18	4.07	22.89	45.2
1569	4	5.86	6.33	4.35	19.96	44.0
1402[1]	1	17.90	....	....	51.10	63.8

[1] Size of coal 60 mesh, all other samples about 10 mesh.

A similar series of experiments (Table 4) was carried out on a small scale in the laboratory with coal of buckwheat size and smaller, both dry and under water. In about eight months every one of these samples showed a positive gain in weight, ranging from ½ to 2 per cent. The coal kept under water showed the smallest average gain. The gain in weight of these samples was probably due to the absorption of oxygen by the coal substance and also to the oxidation of pyrite and marcasite. The gain in weight of bituminous coal upon heating for a short time at a moderate temperature is a phenomenon which has often been noted by chemists working with this substance. In this laboratory a number of air-dry samples were heated to various temperatures from 105° to 260° C. The figures representing the amount of moisture in the coal are given in the column headed "1 hour at 105° C.," Table 5. The same coals heated for four hours at the same temperature show changes in weight in both directions. The first two samples of finely pulverized coal both increased in weight. The 10-mesh samples in one and two-gram lots changed very little, three gaining and three losing in weight. The four portions of sample No. 1569 show the result of increasing the size of the sample without increasing in the same proportion the surface exposed to the air. The larger portions show a greater loss in weight because they do not have the opportunity to absorb so much oxygen on account of the smaller surface exposed. After 18 hours at 140° C., the losses are all smaller than enough to cover the amount of moisture present, thus indicating a gain in weight due to oxidation. The same relative changes in the four portions of sample No. 1569 are still evident. Heating at 260° C., however, causes a striking loss in weight due to the very rapid oxidation at that temperature which is approaching closely the ignition temperature of the coal. In fact, any quantity of coal of more than 100 grams, of the size used in these experiments, would be very apt to ignite if heated to 260° C.[1]

Sampling.—The six cars of coal before mentioned were all inspected at the mine and sampled as they were loaded, to avoid any unknown changes while the coal was in transit. About four hundred pounds was taken at intervals with a scoop from the stream of coal as it comes from the chute, and this sample reduced by quartering to about two pounds, which was sent to the laboratory for immediate analysis. The next series of samples was taken about one week later

[1]Eng. Exp. Sta., U. of I., Bul. 24, S. W. Parr and C. K. Francis, June, 1908.

when the coal was being hauled by wagon from the cars to the storage bins. Occasional shovelfuls were taken as the wagons unloaded, until a sample of about three or four hundred pounds was obtained. This was handled as before by alternate crushings and quarterings until only two pounds remained. At the laboratory this sample after air-drying was crushed to ⅛ inch and smaller, and all further quartering was done with a riffle sampler. When the coal was once in place in the bins, it was thought best not to shovel it over or rehandle it in any way, as any extra handling would change the conditions from those of actual storage and would of course modify any results from sizing tests. To avoid this rehandling, a sampler was designed that would take cores through the whole thickness of the pile without disturbing any of the coal except that taken out as a sample. Ordinarily six cores, seven inches in diameter, were taken from a bin for a sample. This number of holes gave a sample of about 250 to 400 pounds, depending on the depth of the coal in any particular bin. The sampler itself (Fig. 4) is made up of two parts. One is a casing of spiral riveted pipe fitted with a notched shoe to overturn the larger pieces of coal that may be struck as it is forced into the pile. At the top it is protected by a stiffening ring to prevent battering of the pipe. The ring has 1-in. holes in opposite sides to admit the end of a bar or a small piece of pipe to be used as a handle to turn the large pipe, which will usually sink of its own weight, if rotated. This pipe serves only to prevent the coal from caving into the hole. The main part of the sampler is somewhat like a post-hole digger, except that it is fitted with a shutter at the bottom to retain the coal after being filled. It is used to remove the coal from the larger pipe as it is sunk. Casing and sampler are shown in Fig. 6.

VI. Change in Calorific Value

The main part of the present investigation has been devoted to following the changes in calorific value of the actual coal substance. It is impossible to sample any lot of coal exactly as regards ash and sulphur, and for that reason it was found necessary to refer all B. t. u determinations to the actual coal basis[1] for the sake of comparison. For this purpose the following formula was used.

$$\frac{\text{B. t. u. as determined} - 5000 \times \text{Weight of Sulphur}}{1.00 - (\text{Moisture} + 1.08 \times \text{Ash} + 22/40 \times \text{Sulphur})}$$

[1]Bul. No. 37, Eng. Exp. Sta., 1909. S. W. Parr and W. F. Wheeler.

For the benefit of anyone who has not a copy of Bulletin No. 37 at hand, a brief explanation of some of the terms used in the formula follows:

"5000 × Weight of Sulphur" in pounds per pound of coal represents the heating value of the sulphur in B. t. u. This is deducted from the heating value of the coal given by the calorimeter in order to overcome any variation in the amount of sulphur present in the several coal samples. For purposes of comparison, it is found advisable to consider the sulphur as being extraneous matter and not as part of the coal substance. The term "1.08 × Ash" represents the mineral matter of the coal that remains after burning completely, and also an additional eight per cent for the water and carbon dioxide that were not part of the coal, but were chemically combined with the mineral matter of the ash and thus took the place of an equal weight of actual coal. The last term "22/40 × Sulphur" represents the sulphur corrected for the oxygen that replaces it in the ash. When the coal is burned, any sulphur that was combined with iron as pyrite, FeS_2, is replaced by oxygen, leaving Fe_2O_3 in ash. This exchange results in a loss in weight of only 5/8 the amount of sulphur burned. Since part of the sulphur is not combined in the form of pyrites, but is in a form which is non-combustible and may remain in the ash, the fraction 22/40 is taken instead of 25/40 as being more nearly the figure which would properly be applied. The denominator, taken as a whole, gives the weight of actual coal in a unit weight of coal as analyzed."

It was found that coal samples, even when kept sealed in glass jars for a few months, change appreciably in calorific value.[1] To avoid any such changes, the analyses and calorimetric determinations were all made not later in any case than ten days after sampling the coal. The Mahler-Atwater bomb calorimeter with platinum lining using compressed oxygen was used for all calorimeter tests. The calorimeter room is shown in Fig. 7.

The change in calorific value of the coal was found to be most rapid during the first few weeks after mining, but it was found to continue at a decreasing rate for more than a year certainly, and probably it continues indefinitely. The greater losses in calorific value occur in the smaller sizes of coal, the screenings in practically every instance suffering more of a loss than the nut coal. The greatest loss in any instance was found in the Sangamon county screenings.

[1]Bul. No. 17, Eng. Exp. Sta. S. W. Parr and W. F. Wheeler. J. Am. Chem. Soc., Vol. 30, p. 1027

Fig. 6

and that was but 5.14 per cent. The average losses for all sizes and both methods of storage, in open and covered bins, for one year is practically 3 per cent. Tables 6 to 12 inclusive and Fig. 8 to 15 inclusive show the losses for coals from different seams and different storage

Fig. 7

conditions. Table 12 is made up of average values from the six preceding tables, and it seems reasonable to suppose that it shows about what may be expected of Illinois coals when stored. The loss for one year was found to be only 2.76 per cent when exposed to the weather, against 3.14 per cent when in covered bins, and 1.49 per cent when stored under water. Nearly one-third of the loss took place during shipment, except in the case of the coal stored under water, when more than one-half of the loss occurred in the first week. None of the losses in calorific value thus far noted are great enough to warrant any changes in present storage methods, but there is a possibility that protection from spontaneously ignited fires and lessened breakage may make storage under water advisable in many instances.

The Christian county coal heated to a considerable extent and

TABLE 6

VERMILION COUNTY, ILLINOIS, NUT COAL

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal[1]	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
	Stored in Exposed Bins						
1031	Same day as mined.....	10.55	4.25	12991	14814	.....	.....
1081	7 days after mining.....	13.98	2.65	12412	14716	98	.66
1240	2 months " "	14.21	2.47	12265	14577	237	1.60
1656	6 " " "	13.53	2.10	12396	14575	239	1.61
2088	1 year " "	13.62	2.82	12282	14498	316	2.13
	Stored in Covered Bins						
1031	Same day as mined.....	10.55	4.25	12991	14814	...	....
1081	7 days after mining.....	13.98	2.65	12412	14716	98	.66
1249	2 months " "	13.08	2.13	12475	14604	210	1.42
1662	6 " " "	11.76	2.14	12571	14472	342	2.31
2094	1 year " "	13.52	2.72	12220	14403	411	2.77
	Stored under Water						
1031	Same day as mined.....	10.55	4.25	12891	14814	...	....
1081	" " " submerged.....	13.98	2.65	12412	14716	98	.66
1647	6 months after mining.....	15.37	3.34	12013	14524	290	1.96
2100	1 year " "	13.85	3.81	12231	14517	297	2.00

[1] For meaning of actual or unit coal, see formula on page 23.

caught fire several times, the fire in each case being extinguished by a large quantity of water. Even in this case the loss was not of a very serious nature, being less than 3 per cent, only a little higher than would have occurred if the coal had not heated at all.

The coal from Fulton county showed a small decrease, only 0.7 per cent, in calorific value, when compared with coal two weeks after mining. If a fresher sample of coal had been available for determining the original B. t. u. value, the loss shown would have been at least double that found. The analyses of the coals from Christian and Fulton counties are found in Table 13.

For some unknown reason, the losses in calorific value shown in Table 14 for the second lot of Vermilion county screenings after about two and one-half years' storage are less than might be expected considering the losses shown by the other coal from the same county.

TABLE 7

WILLIAMSON COUNTY, ILLINOIS, NUT COAL

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
	Stored in Exposed Bins						
1090 1091	Same day as mined.....	13.98	3.73	12499	14859	...	....
1098	7 days after mining.....	14.90	3.02	12341	14821	38	.26
1246	2 months " "	14.32	4.12	12409	14835	24	.16
1657	6 " " "	13.81	3.45	12455	14765	95	.64
2090	1 year " "	11.88	2.73	12759	14734	125	.84
	Stored in Covered Bins						
1090 1091	Same day as mined.....	13.98	3.73	12499	14859	...	....
1098	7 days after mining.....	14.90	3.02	12341	14821	38	.26
1247	2 months " "	14.08	3.84	12378	14739	120	.81
1663	6 months " "	13.06	3.60	12469	14644	215	1.45
2096	1 year " "	13.24	3.20	12428	14616	243	1.64
	Stored under Water						
1090 1091	Same day as mined.....	13.98	3.73	12499	14859	...	....
1098	" " " submerged.....	14.90	3.02	12341	14821	38	.26
1648	6 months after mining.....	15.65	3.12	12097	14673	186	1.25
2102	1 year " "	14.87	3.42	12251	14721	138	.93

(See Tables 6 and 9.) The changes for the second year are shown to be only about one-half those for the first year. However, in this case, the coal seems to have reached a stage where the loss occurs at a uniform rate of about 0.1 per cent per month where the coal is stored without protection from the weather.

About fifteen months after mining, one sample was taken from this lot of coal to represent the whole pile and another to represent the outside six inches of the pile, with the expectation that the surface layers would show greater losses than the whole mass. The calorific values of the two samples, however, varied by only a few B. t. u., not a difference greater than the limit of accuracy of the determination.

Coal that will weather in the open air ought to weather to almost

TABLE 8

SANGAMON COUNTY, ILLINOIS, NUT COAL

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
	Stored in Exposed Bins						
1078	Same day as mined.....	17.87	5.75	11741	14773	.....	....
1084	7 days after mining.....	16.63	5.10	11800	14571	202	1.37
1248	2 months " "	17.45	4.66	11626	14497	276	1.87
1658	6 " " "	16.03	4.91	11798	14444	329	2.23
2086	1 year " "	14.97	4.68	11860	14307	466	3.15
	Stored in Covered Bins						
1078	Same day as mined.....	17.87	5.75	11741	14773	....	.....
1084	7 days after mining.....	16.63	5.10	11800	14571	202	1.37
1250A	2 months " "	16.08	5.03	11912	14600	173	1.17
1250B	2 " " "	17.57	5.01	11626	14535	238	1.61
1664	6 " " "	16.30	4.52	11682	14336	437	2.96
2092	1 year " "	15.99	4.65	11589	14165	608	4.12
	Stored under Water						
1078	Same day as mined.....	17.87	5.75	11741	14773	...	....
1084	" " " submerged.....	16.63	5.10	11800	14571	202	1.37
1649	6 months after mining.....	15.90	4.21	11854	14461	322	2.18
2098	1 year " "	15.95	5.11	11851	14503	270	1.83

as great an extent when exposed in the mine, but samples taken from old pillars in two Illinois mines, after an exposure for about twenty-five years, show less than three per cent loss in either case. The coal showed no shrinkage or change in physical appearance in either of these pillars after about one-half inch of dirty coal was removed from the surface. The analyses of these samples of old coal and of a sample from an outcrop in Peoria county are presented in Table 15. This outcrop coal represents the greatest deterioration that has so far come to our knowledge. In fact, the sample from the outcrop shows almost a complete change in the character of the coal. It has every physical appearance of a brown lignite, while the unaltered coal from the same seam was a fair grade of bituminous coal not different from other Illinois coals. This change appears to be in the wrong direction to agree with most of the accepted theories of coal formation. Most of the writers on coal formation think that our coal deposits

TABLE 9

VERMILION COUNTY, ILLINOIS, SCREENINGS

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
	Stored in Exposed Bins						
1032	Same day as mined	17.88	2.35	11937	14888	...	....
1080	7 days after mining	13.98	2.87	12414	14726	162	1.09
1082	7 " " "	13.69	2.29	12507	14759	129	.87
1238	2 months " "	15.73	2.53	11958	14497	391	2.63
1239	2 " " "	14.69	2.90	12178	14578	310	2.08
1653	6 " " "	15.63	2.44	11969	14487	401	2.69
2089	1 year " "	14.46	2.24	12006	14304	584	3.92
	Stored in Covered Bins						
1032	Same day as mined	17.88	2.35	11937	14888	...	....
1080	7 days after mining	13.98	2.87	12414	14726	162	1.09
1082	7 " " "	13.69	2.29	12507	14759	129	.87
1241	2 months " "	15.26	2.51	12124	14608	280	1.88
1659	6 " " "	14.51	2.25	12071	14391	497	3.34
2095	1 year " "	15.36	2.42	11797	14225	663	4.46
	Stored under Water						
1032	Same day as mined	17.88	2.35	11937	14888	...	....
1080	" " " submerged	13.98	2.87	12414	14726	162	1.09
1082	" " " "	13.69	2.29	12507	14759	129	1.87
1644	6 months after mining	13.87	2.32	12270	14514	374	2.51
2101	1 year " "	13.55	2.71	12283	14483	405	2.72

have gone through the various stages from peat to anthracite. In this case the sulphur is almost free from the coal, supposedly by oxidation and leaching. The thickness of the No. 5 coal seam is remarkably uniform in this locality, and the thickness of the outcrop coal is not different from the thickness of the seam in other places near-by where the coal is unchanged. Thus, no evidence is offered that the seam at this place had suffered any very great shrinkage.

The coal stored by the Commonwealth Edison Company of Chicago was sampled after fifteen months' storage and losses of only about one per cent were found, although the final samples were taken from the surface of the piles. (See analytical results, Table 16.) The

TABLE 10

WILLIAMSON COUNTY, ILLINOIS, SCREENINGS

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
	Stored in Exposed Bins						
1089	Same day as mined	14.13	3.17	12426	14782	...	....
1099	7 days after mining	14.37	3.34	12287	14666	116	.78
1244	2 months " "	15.66	2.67	12133	14701	81	.55
1654	6 " " "	13.76	2.84	12342	14597	185	1.25
2091	1 year " "	13.77	2.75	12328	14579	203	1.37
	Stored in Covered Bins						
1089	Same day as mined	14.13	3.17	12426	14782	...	....
1099	7 days after mining	14.37	3.34	12287	14666	116	.78
1245	2 months " "	12.62	2.98	12608	14705	77	.52
1660	6 " " "	13.60	3.03	12372	14610	172	1.16
2097	1 year " "	13.43	2.72	12385	14582	200	1.35
	Stored under Water						
1089	Same day as mined	14.13	3.17	12426	14782	...	....
1099	" " " submerged	14.37	3.34	12287	14666	116	.78
1645	6 months after mining	14.38	3.54	12262	14645	137	.93
2103	1 year " "	13.60	2.97	12447	14698	84	.57

coal in these large piles seemed to have broken up very slightly, and no objectionable heating was noticed.

VII. CONCLUSIONS

Coal of the type found in Illinois and neighboring states is not affected seriously during storage when only the changes in weight and losses in heating power are considered. The changes in weight may be either gains or losses of probably never over two per cent in a period of one year. The heating value decreases most rapidly during the first week after mining and continues to decrease more and more slowly for an indefinite time. In the coals that have been tested, one per cent is about the average loss for the first week and three to three and one-half per cent would cover the losses for a year,

TABLE 11

SANGAMON COUNTY, ILLINOIS, SCREENINGS

Lab. No.	Sample Taken	Dry Coal-			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u		B. t. u.	per cent
	Stored in Exposed Bins						
1079	Same day as mined.	17.13	4.92	11752	14604	...	....
1085	7 days after mining.	17.04	4.47	11684	14481	123	.84
1242	2 months " "	17.22	5.00	11645	14488	116	.79
1655	6 " " "	17.02	4.54	11526	14281	323	2.21
2087	1 year " "	17.25	4.54	11153	13853	751	5.14
	Stored in Covered Bins						
1079	Same day as mined.	17.13	4.92	11752	14604	...	....
1085	7 days after mining. .	17.04	4.47	11684	14481	123	.84
1243	2 months " "	18.33	4.70	11414	14404	200	1.37
1661	6 " " "	17.30	4.67	11466	14263	341	2.33
2093	1 year " "	17.06	4.73	11248	13944	660	4.52
	Stored under Water						
1079	Same day as mined.	17.13	4.92	11752	14604	...	....
1085	" " " submerged.	17.04	4.47	11684	14481	123	.84
1646	6 months after mining.	19.86	5.60	11127	14372	232	1.59
2099	1 year " " "	18.27	4.81	11479	14478	126	.86

although in some instances the loss was found to be as high as five per cent in a year.

The losses due to disintegration of the coal and to spontaneous ignition seem to be of far greater importance than any changes in weight and heating value, although they cannot be expressed in figures for comparison. The storage of coal of a size larger than is to be used would overcome part of this objection to storage, as the coal could be crushed to the most advantageous size just before firing. The larger sizes of coal are also much less liable to take fire spontaneously. Storage under water will prevent disintegration of the coal to a very large extent, and it will absolutely prevent any fire losses. Aside from these advantages in favor of storing coal under water, there seems to be very little to be said in favor of any particular method of storing coal.

TABLE 12

AVERAGE VALUES FROM SIX PRECEDING TABLES

	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal[1]	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
	Stored in Exposed Bins						
....	Same day as mined.....	15.26	4.03	12224	14787	...	....
....	7 days after mining.....	15.13	3.53	12164	14666	121	.82
....	2 months " "	15.68	3.61	12024	14606	181	1.22
....	6 " " "	14.96	3.36	12081	14525	262	1.77
....	1 year " "	14.33	3.29	12065	14379	408	2.76
	Stored in Covered Bins						
....	Same day as mined.....	15.26	4.03	12224	14787	...	....
....	7 days after mining.....	15.13	3.53	12164	14666	121	.82
....	2 months " "	15.07	3.53	12128	14605	182	1.22
....	6 " " "	14.42	3.37	12105	14453	334	2.26
....	1 year " "	14.77	3.57	11945	14323	464	3.14
	Stored under Water						
....	Same day as mined.....	15.26	4.03	12224	14787	...	....
....	" " " submerged.....	15.13	3.53	12164	14666	121	.82
....	6 months after mining.....	15.84	3.69	11937	14532	255	1.73
....	1 year " "	15.02	3.81	12090	14567	220	1.49

TABLE 13

CHRISTIAN COUNTY, ILLINOIS, SCREENINGS

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
....	When stored (about 2 weeks after mining).....	19.20	5.04	11325	14475	...	....
1422	Five months in exposed pile of 500 tons (had heated badly).....	16.68	4.43	11425	14083	392	2.71
	FULTON COUNTY, ILLINOIS, SCREENINGS.						
1405	Two weeks after mining....	20.97	3.42	11114	14500	....	....
1406	Six months in exposed pile three feet deep.....	21.12	3.17	11021	14398	1.02	.70

[1] For meaning of actual or unit coal, see formula on page 23.

TABLE 14

VERMILION COUNTY, ILLINOIS, SCREENINGS

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal[1]	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	per cent
	In Exposed Pile						
....	When mined.....	.....	....	.....	14850[2]	...	....
144	About two weeks after mining.....	19.11	1.96	11561	14644	206	1.39
973	15 months after mining.....	19.54	2.20	11368	14491	359	.42
1627	22 " " "	20.61	1.88	11134	14392	458	3.08
2104	28 " " "	21.70	1.83	10901	14307	543	3.66
	Stored under Water						
....	When mined.....	.....	.....	.....	14850	...	....
975	15 months after submerging.	15.90	2.29	12154	14761	89	.60
2105[3]	28 " " "	17.75	1.97	11686	14531	319	2.15

[1] Calorific value taken from other analyses of fresh coal from same mine and neighboring mines.

[2] Coal was not completely covered with water for last two months.

[3] For meaning of actual or unit coal, see formula on page 23.

TABLE 15

ANALYSES OF PILLAR-COAL AND OUTCROP COAL COMPARED WITH FRESH COAL

Lab. No.	Description	Total Moisture	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
			Ash	Sulphur	B. t. u.		B. t. u.	per cent
	ST. CLAIR COUNTY, ILLINOIS							
991	Fresh Coal.....	9.76	15.80	4.76	12202	14896	...	....
992	Pi lar-coal exposed 22 years.....	10.18	16.21	5.01	11797	14482	414	2.78
	GALLATIN COUNTY, ILLINOIS							
1092	Fresh coal.....	4.47	10.85	3.72	13235	15133	...	....
1093	Pillar-coal exposed 27 years.....	4.76	13.84	3.84	12514	14857	276	1.82
	PEORIA COUNTY, ILLINOIS							
1407	Fresh coal.....	13.86	16.25	3.91	12044	14757	...	....
1402	Outcrop coal, slightly covered with soil.....	29.81	16.86	.85	9257	11331	3426	23.21

TABLE 16

COMMONWEALTH EDISON COMPANY, CHICAGO

Stored Coal

Lab. No.	Sample Taken	Dry Coal			B. t. u. Referred to Actual or Unit Coal[1]	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u	per cent
	FRANKLIN CO., ILLINOIS						
	Nut Coal						
1337 1414	April, 1908	10.16	1.81	13021	14688	....	....
2619	July 14, 1909	10.44	2.15	12924	14642	46	.31
	WILLIAMSON COUNTY AND FRANKLIN COUNTY, ILLINOIS						
	Egg Coal						
1335 1415	April, 1908	10.97	2.35	12909	14728	...	....
2620	July 14, 1909	11.49	1.84	12697	14559	169	1.15
	WILLIAMSON CO., ILLINOIS						
	No. 1 Washed Nut						
1336 1416	April, 1908	9.21	1.82	13205	14726	...	....
2618	July 14, 1909	9 43	1.72	13008	14540	186	1.26

[1] For meaning of actual or unit coal, see formula, p. 23.

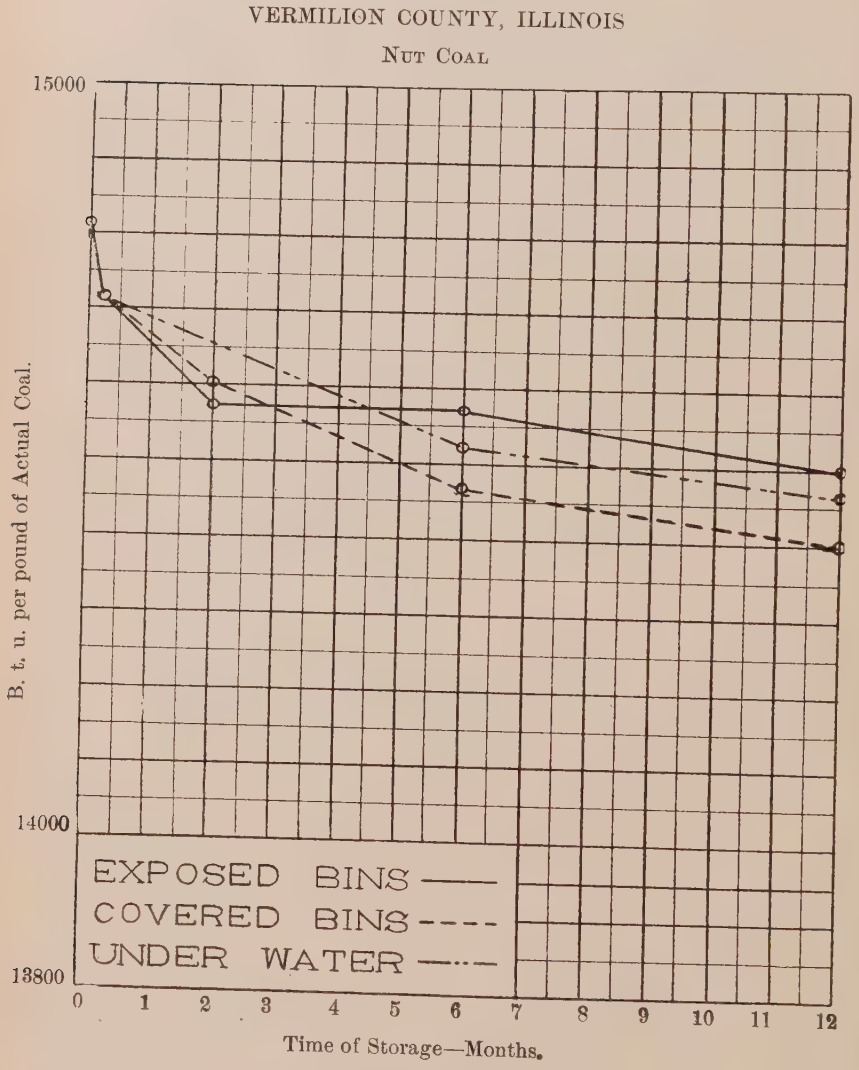

VERMILION COUNTY, ILLINOIS
Nut Coal
15000
14000
13800
B. t. u. per pound of Actual Coal.
EXPOSED BINS
COVERED BINS
UNDER WATER
0
1
2
3
4
5
6
7
8
9
10
11
12
Time of Storage—Months.

Fig. 8

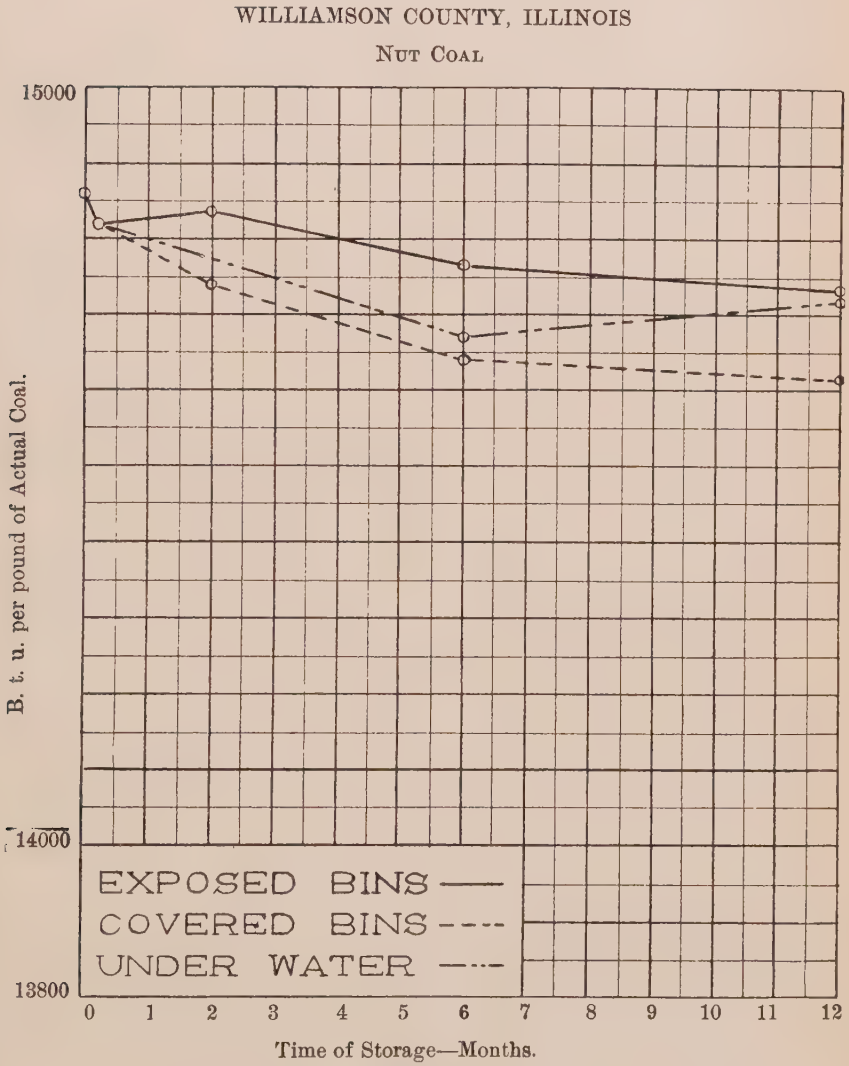

WILLIAMSON COUNTY, ILLINOIS
Nut Coal
15000
14000
13800
B. t. u. per pound of Actual Coal.
EXPOSED BINS
COVERED BINS
UNDER WATER
0 1 2 3 4 5 6 7 8 9 10 11 12
Time of Storage—Months.

Fig. 9

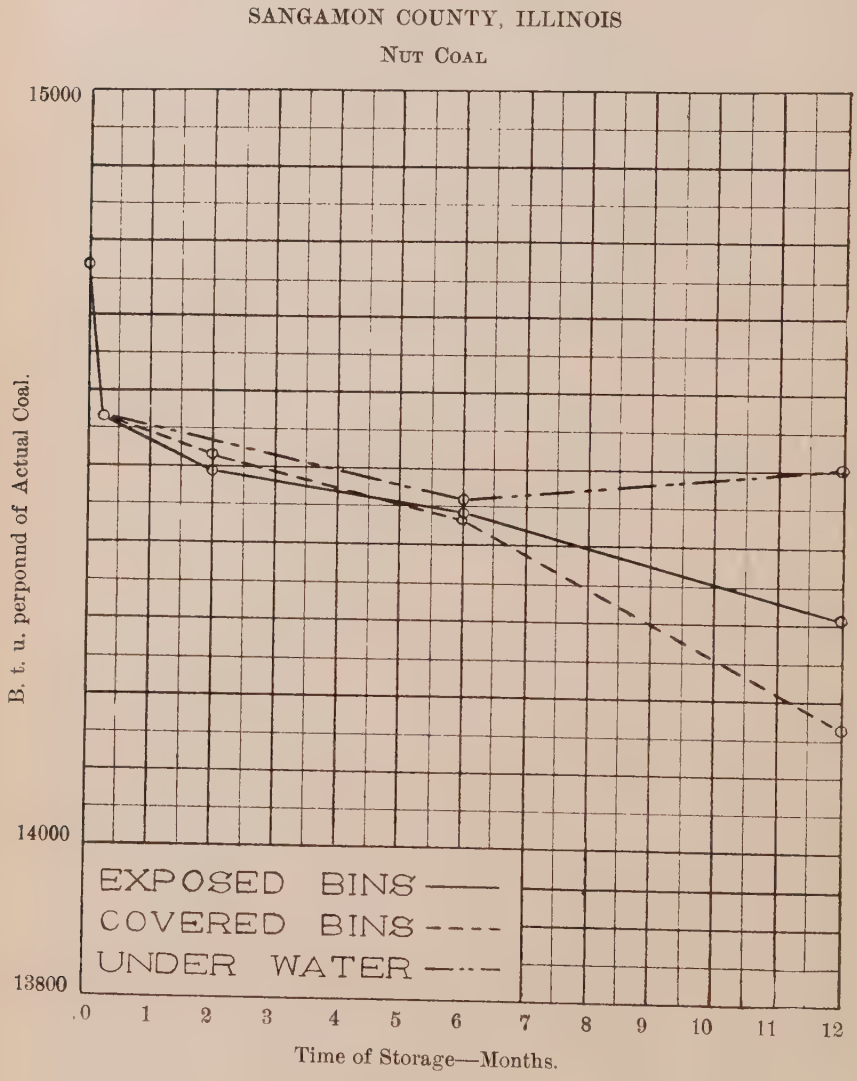

SANGAMON COUNTY, ILLINOIS
Nut Coal
15000
14000
13800
B. t. u. perpound of Actual Coal.
EXPOSED BINS
COVERED BINS
UNDER WATER
.0
1
2
3
4
5
6
7
8
9
10
11
12
Time of Storage—Months.

Fig. 10

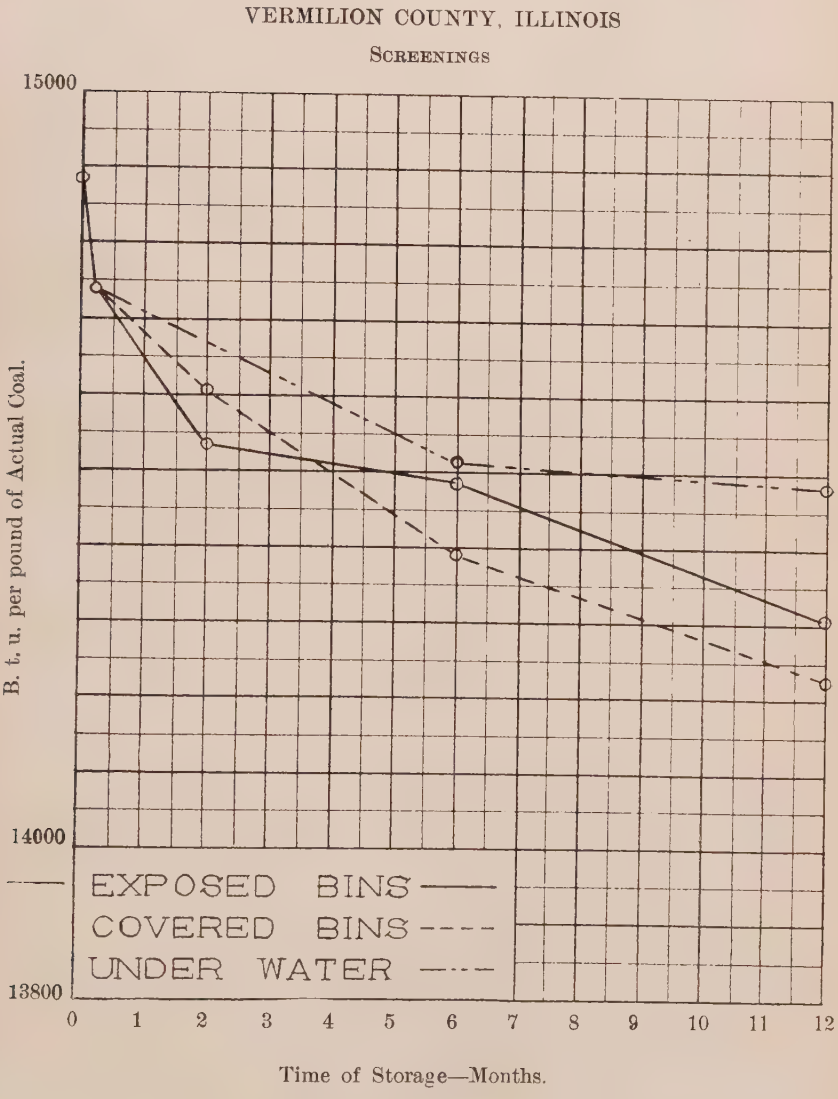

VERMILION COUNTY, ILLINOIS
Screenings
15000
14000
13800
B. t. u. per pound of Actual Coal.
EXPOSED BINS
COVERED BINS
UNDER WATER
0
1
2
3
4
5
6
7
8
9
10
11
12
Time of Storage—Months.

Fig. 11

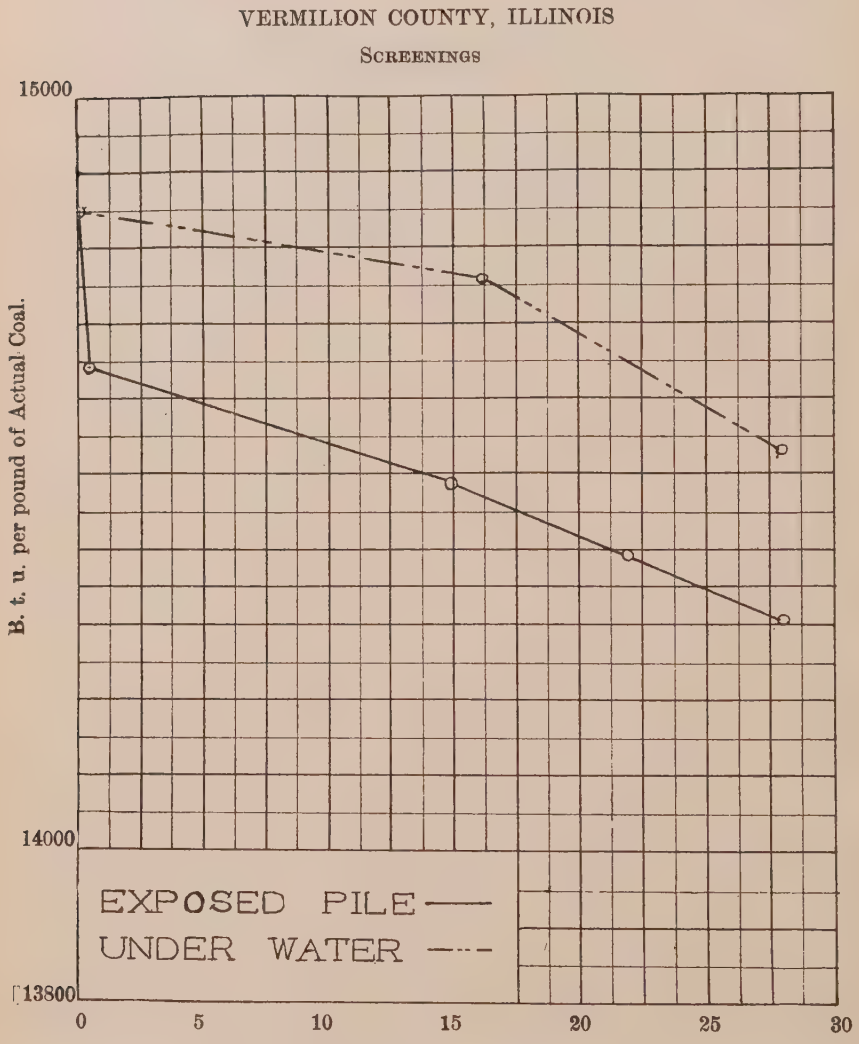

VERMILION COUNTY, ILLINOIS
Screenings
15000
14000
13800
B. t. u. per pound of Actual Coal.
EXPOSED PILE ——
UNDER WATER - - -
0
5
10
15
20
25
30
Time of Storage—Months.

Fig. 12

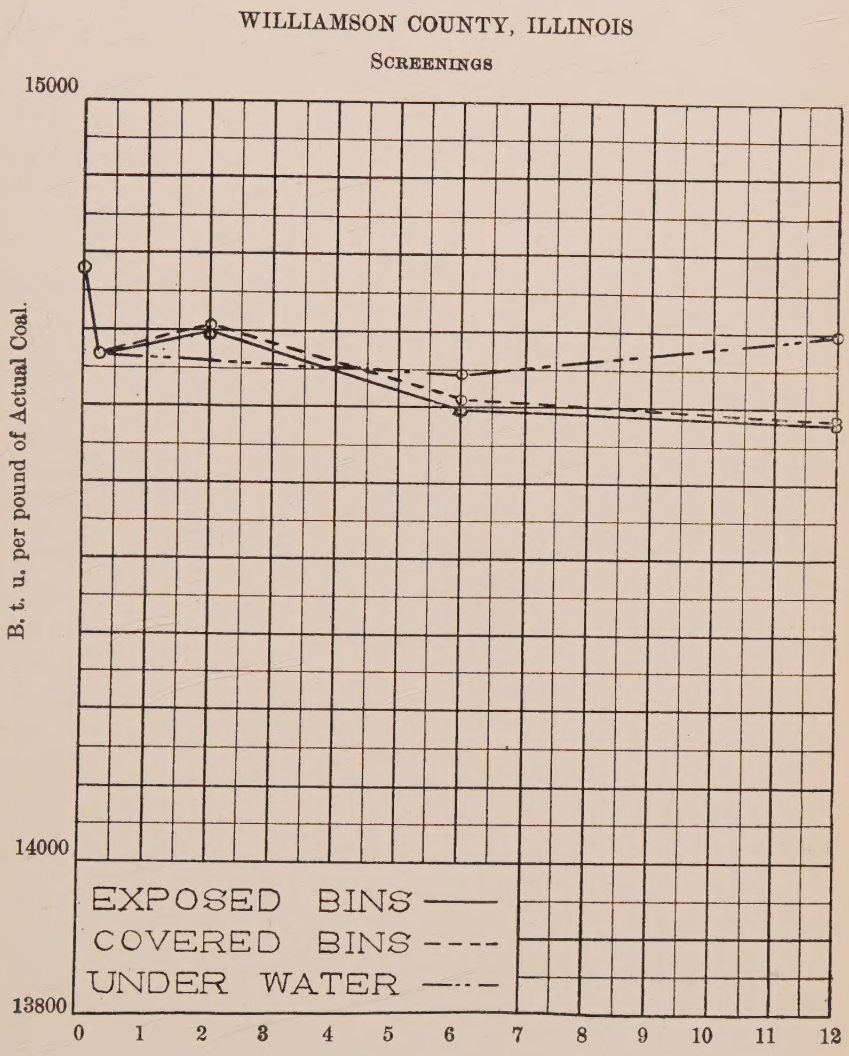

WILLIAMSON COUNTY, ILLINOIS
SCREENINGS
15000
14000
13800
B. t. u. per pound of Actual Coal.
EXPOSED BINS
COVERED BINS
UNDER WATER
0
1
2
3
4
5
6
7
8
9
10
11
12
Time of Storage—Months.

Fig. 13

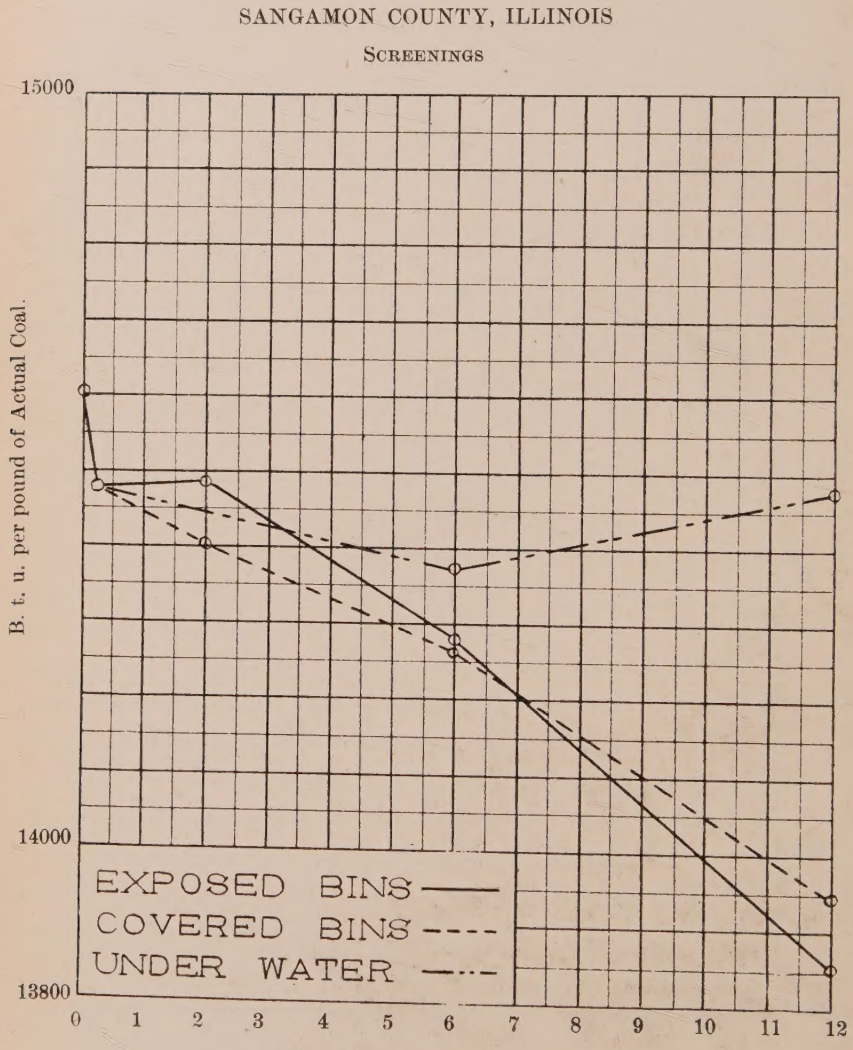

SANGAMON COUNTY, ILLINOIS
Screenings
15000
14000
13800
B. t. u. per pound of Actual Coal.
EXPOSED BINS
COVERED BINS
UNDER WATER
0 1 2 3 4 5 6 7 8 9 10 11 12
Time of Storage—Months.

Fig. 14

AVERAGE VALUES FROM THE SIX PRECEDING TABLES.

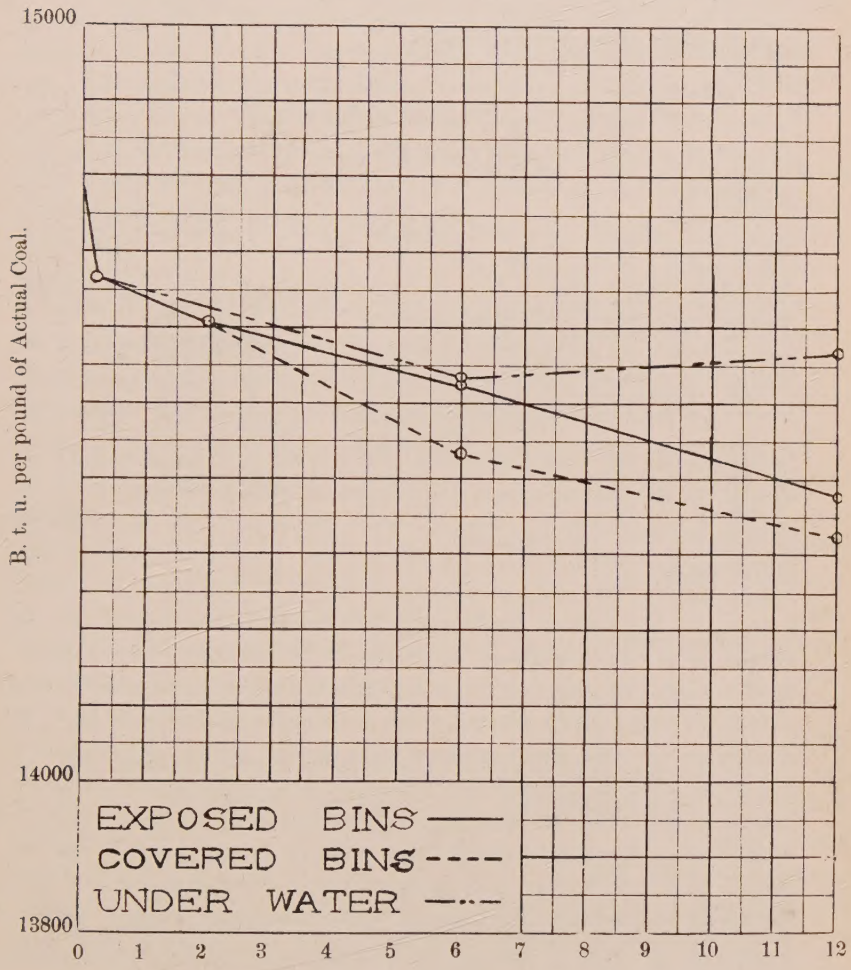


Fig. 15

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. (*Out of print.*)

Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. (*Out of print.*)

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. (*Out of print.*)

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906. (*Out of print.*)

Circular No. 3. Fuel Tests with Illinois Coal. (Compiled from tests made by the Technologic Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907, by L. P. Breckenridge and Paul Diserens. 1909.

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. (*Out of print.*)

Bulletin No. 4. Tests of Reinforced Concrete Beams. Series of 1905, by Arthur N. Talbot. 1906.

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman. 1906. (*Out of print.*)

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906. (*Out of print.*)

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr and Henry B. Dirks. 1906. (*Out of print.*)

Bulletin No. 8. Tests of Concrete: I. Shear; II. Bond, by Arthur N. Talbot. 1906. (*Out of print.*)

Bulletin No. 9. An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906.

Bulletin No. 10. Tests of Concrete and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot. 1907. (*Out of print.*)

Bulletin No. 11. The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907. (*Out of print.*)

Bulletin No. 12. Tests of Reinforced Concrete T-beams, Series of 1906, by Arthur N. Talbot. 1907. (*Out of print.*)

Bulletin No. 13. An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1907.

Bulletin No. 14. Tests of Reinforced Concrete Beams, Series of 1906, by Arthur N. Talbot. 1907. (*Out of print.*)

Bulletin No. 15. How to Burn Illinois Coal without Smoke, by L. P. Breckenridge. 1908.

Bulletin No. 16. A Study of Roof Trusses, by N. Clifford Ricker. 1908.

Bulletin No. 17. The Weathering of Coal, by S. W. Parr, N. D. Hamilton, and W. F. Wheeler. 1908. (*Out of print.*)

Bulletin No. 18. The Strength of Chain Links, by G. A. Goodenough and L. E. Moore. 1908.

Bulletin No. 19. Comparative Tests of Carbon, Metallized Carbon and Tantalum Filament Lamps, by T. H. Amrine. 1908.

Bulletin No. 20. Tests of Concrete and Reinforced Concrete Columns, Series of 1907, by Arthur N. Talbot. 1908.

Bulletin No. 21. Tests of a Liquid Air Plant, by C. S. Hudson and C. M. Garland. 1908.

Bulletin No. 22. Tests of Cast-Iron and Reinforced Concrete Culvert Pipe, by Arthur N. Talbot. 1908.

Bulletin No. 23. Voids, Settlement and Weight of Crushed Stone, by Ira O. Baker. 1908.

Bulletin No. 24. The Modification of Illinois Coal by Low Temperature Distillation, by S. W. Parr and C. K. Francis. 1908.

Bulletin No. 25. Lighting Country Homes by Private Electric Plants, by T. H. Amrine. 1908.

Bulletin No. 26. High Steam-Pressures in Locomotive Service. A Review of a Report to the Carnegie Institution of Washington. By W. F. M. Goss. 1908.

Bulletin No. 27. Tests of Brick Columns and Terra Cotta Block Columns, by Arthur N. Talbot and Duff A. Abrams. 1909.

Bulletin No. 28. A Test of Three Large Reinforced Concrete Beams, by Arthur N. Talbot. 1909.

Bulletin No. 29. Tests of Reinforced Concrete Beams: Resistance to Web Stresses, by Arthur N. Talbot. 1909.

Bulletin No. 30. On the Rate of Formation of Carbon Monoxide in Gas Producers, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1909.

Bulletin No. 31. Fuel Tests with House-heating Boilers, by J. M. Snodgrass. 1909.

Bulletin No. 32. Occluded Gases in Coal, by S. W. Parr and Perry Barker. 1909.

Bulletin No. 33. Tests of Tungsten Lamps, by T. H. Amrine and A. Guell. 1909.

Bulletin No. 34. Tests of Two Types of Tile Roof Furnaces under a Water-Tube Boiler, by J. M. Snodgrass. 1909.

Bulletin No. 35. A Study of Base and Bearing Plates for Columns and Beams, by N. C. Ricker. 1909.

Bulletin No. 36. The Thermal Conductivity of Fire-Clay at High Temperatures, by J. K. Clement and W. L. Egy. 1909.

Bulletin No. 37. Unit Coal and the Composition of Coal Ash, by S. W. Parr and W. F. Wheeler. 1909.

Bulletin No. 38. The Weathering of Coal, Series of 1909, by S. W. Parr and W. F. Wheeler. 1909.